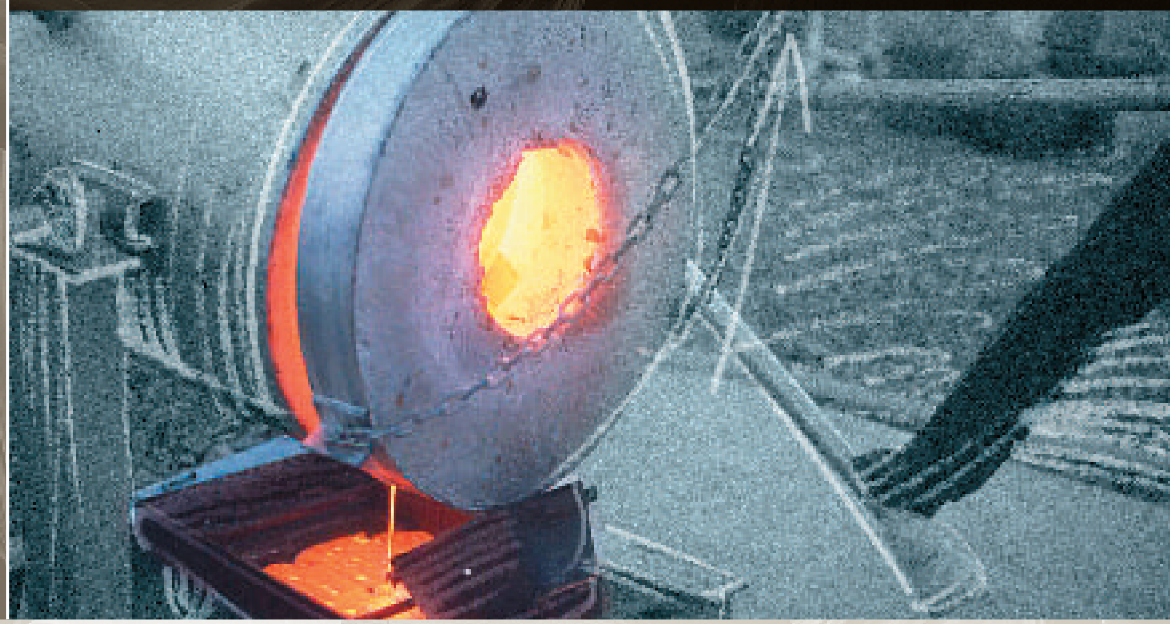
Life cycle assessment (LCA) for the metals cycle in the context of waste policy

The general trend in waste policy making goes towards integrating the waste sector in the holistic environmental assessment approach "Building on environmental Life Cycle thinking". How can LCA support this trend in the field of metals?



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LCA as a central piece of scientific support to waste policy

The waste management policy in the EU is rapidly evolving. The major objective of this evolution is a de-coupling between economic growth and waste production and a reduction of environmental impacts associated with the generation and management of waste [see EC Communication COM(2003) 301 final: *"Towards a thematic strategy for the prevention and recycling of waste"*, 14 April 2003].

A number of concepts have been widely recognised as guiding policy principles for waste management with the aim of reducing environmental impacts of waste both in terms of quantity and quality. These principles include: prevention principle, precautionary principle, proximity principle, polluter pays principle and principle on extended producer responsibility. The principles are often translated into what is known as waste management hierarchy, which prioritises the actions to be taken in the following: waste prevention and reduction, reuse, recycling, environmentally sound treatment and disposal and improved monitoring. To help setting up these principles, research projects have been conducted in the field of municipal waste [2].

Thus the general trend goes towards integrating the waste sector in the holistic environmental assessment approach "building on environmental Life Cycle Thinking",

which also serves as the basis for the Communication on Integrated Product Policy COM(2003) 302 final from June 2003, the IPPC-system (Integrated Pollution Prevention and Control) for industrial facilities (including waste treatment) and the European Soil strategy.

To this end, life cycle assessment (LCA) is a key step to quantify environmental impacts. LCA can be defined as an iterative procedure to quantify and interpret the environmental repercussions of (changes in) a product system from cradle to crave related to a functional service unit. According to the ISO 14040, LCA includes four phases. After definition of the goal and scope of the study, the resource depletion due to emissions to soil, water and air, material and energy consumption during the entire life cycle is compiled and allocated to the processes or products under investigation *in the inventory analysis* (LCI). The subsequent *impact assessment* (LCIA) involves aggregation, characterisation and normalisation of the resulting inventory results. Aggregation is necessary, as large sets of data cannot easily be dealt with in decision-making [5]. *The final interpretation* involves a sensitivity analysis and a general appraisal.

Stake and limits of LCA

The value of a LCA is related to what extent it increases our ability to anticipate (a) the environmental consequences of using technological systems and their products and (b) the effect of manipulating said systems. Thus, a LCA should provide an as clear as comprehensive picture of the environmental repercussions of our actions. The LCA should yield said repercussions in case contemplated, well-defined alternative actions are assessed, but also when our goal is to generate ideas and a knowledge-base to help decision-making on future systems that are not yet contemplated. In painting such pictures by LCA, typical difficulties encountered include [3]:

- dealing with limited data availability and quality,
- determining allocation rules,
- selection of system boundaries and detail,
- temporal and spatial characteristics,
- final weighting into environmental repercussions.

Among others due to the iterative nature of LCAs, these problems are interrelated. For instance, the availability of many data points can be used to improve data quality, while high quality reduces need for quantity. Study scope, resolution, and boundaries establish the need for data, and vice versa data availability can affect scope, resolution, and system boundaries.

Based on impact assessment two types of LCA can be distinguished: problem-oriented, and damage-oriented. The use of the standardised LCA method at European level as reported by ADEME [1] can be characterised as a damage-oriented or top-down method for life cycle assessment, an approach that is similar to, for example, the Eco-indicator 99 method [4]. This method is often used in product design because it can produce single environmental scores.
Particularly on various packaging materials many LCA studies have been completed. Steel, aluminium and tin are used as packaging material, and said damage-oriented assessments largely focused on traditional steps in the life cycle.

Metals cycle: is it “LCAble”?

Winning, extraction and processing of iron, aluminium and any other metal are part of the inter-connected worldwide metals production system. In this complex, networked system two types of primary metals can be distinguished: carrier and downstream metals. Carrier-metals are metals that flow through the system, which in their primary

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production deliver their co-elements *(Fig. 1)* and in their recycling allow removal of same co-elements from diverse types of materials to be recycled. As such, both primary and secondary production infrastructures for these metals (e.g. copper, nickel, iron) are essential for the functioning of the entire networked metal system and the availability of downstream metals such as cobalt and ruthenium. By reducing the capacity for primary and secondary production of carrier metals, input and recovery capacity of the downstream metals in the networked production system are also unavoidably removed. Thereby, availability is affected of downstream metals at an industry-compatible grade, as well as recovery capacity for harmful downstream heavy metals. The environmental repercussions of these actions are not included in LCA-scores. Obviously these may have a significant impact on life cycle impacts assessments, the extent of which is of course dependent on the weighting of these production and recovery functions in the LCA procedure.

When in the inventory analysis of a damage-oriented LCA, the complex metal production system must be simplified to allow analysis, it could be argued that *Figure 1* should be kept in mind: it illustrates which metals are connected to which metals, and how, and may help to avoid the exclusion of relevant impacts in a LCA.

In recent work [6, 7], a *problem-oriented* LCA for integrated metals cycles has been set up, which allows in-depth analysis of the impact arising from the development and use of products (consumer goods), which bring together metals that are not naturally linked. Such products represent a formidable problem at their end-of-life that can be understood through the information represented in *Figure 1*. Therein, the primary and secondary metals processing infrastructure developed for the processing of combinations of metals as they naturally occur in the Earth's crust is indicated. Its implication is that for any new combination of metals in consumer products no dedicated infrastructure is currently in existence, whilst the risk of co-processing in existing infrastructure often simply is too large. Therefore, to ensure optimal metal recovery product designers must keep this *Figure 1* in mind since this will enable the metal producing industry to optimally deal with end-of-life products and hence improve the overall environmental performance. As such a high level of recovery, in particular recycling can be achieved, and producers can better integrate recycled material in new equipment as promoted in the Directive on waste from electrical and electronic equipment.

Key issue in metals cycle assessment

Metals are generally obtained from the world market and consequently these are metals produced by a network of interconnected production routes, rather than a single production chain [6, 7]. The different production routes in the network differ significantly in their environmental impacts. At the level of individual processes the distinction between recovery and production is fuzzy, and the production of one metal often is

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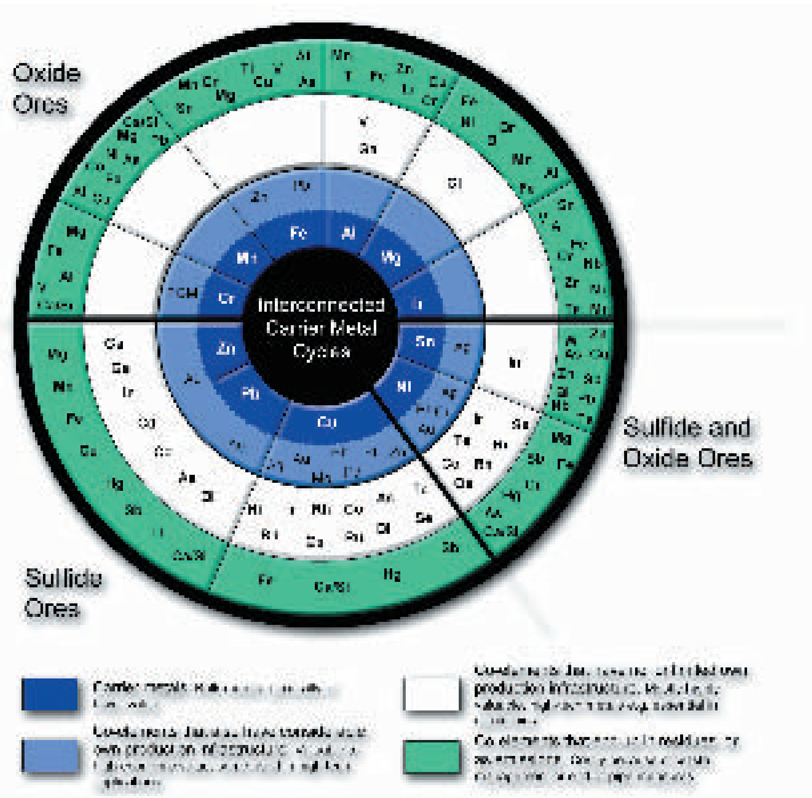


Fig. 1: Metallurgical interconnections of carrier metals and their downstream metals.
Fig. 1 : Interconnexions métallurgiques des métaux porteurs et de leurs métaux associés.

Source: E. Verhoef - M. A. Reuter - G. P. J. Dijkema - A. Scholte [6, 7]

interrelated to and dependent on the consumption or generation of another. Scrap metal is used in primary processes. For instance, in exothermic converting processes, such as the treatment of copper matte for production, scrap is added to control process temperature. In this sense 'primary' copper does not exist, because virtually always a certain percentage of the input is copper scrap or recycled material. Moreover, the recycling of copper from brass scrap, or the steel from cars also produces zinc. Silver, for example, is mainly produced from the by-products of gold, copper, lead and zinc production. Therefore the silver production is affected if the primary production of the aforementioned materials changes. In the case that outlets for arsenic cease to exist (e.g. enforced by legislation), primary production of copper, lead and zinc must be modified or even eliminated. Thus the recovery of one material can interrelate to the recovery of another and the manufacturing of any metal containing product is considered a global, interconnected open loop recycling and production system.

Current EU Regulations do not take these interrelations into account and therefore comes to legislation that could be potentially harmful to waste management at large. Policy being focused on final waste abatement, many options for co-processing and co-incineration that are technically and economically feasible and ecologically sound cannot be realised if a more systems view to waste processing is not adopted. Some prerequisites of sustainability such as minimising material loss and maximising recovery are part of the realm of Solid Waste Management. In order to close material cycles waste must be recovered rather than disposed of.

Methodology

The need is thus of developing an interconnected dynamic system model that:

► Interrelates the metal production systems of the major metals depicted in *Figure 1*,

► Creates a static and dynamic model to provide outputs for environmental assessments by linking the output of the dynamic model to LCA tools *(see Fig. 2)*,

► Links the metal industry with the waste infrastructure and end-of-life product processing *(see Fig. 2)*,

► Incorporates present and future restrictions or opportunities caused by EU Legislation into the models,

► Supports problem-oriented LCA approach for policy analysis to ensure that legislation does not become too restrictive or even harmful to the creation of an industrial ecological sound system.

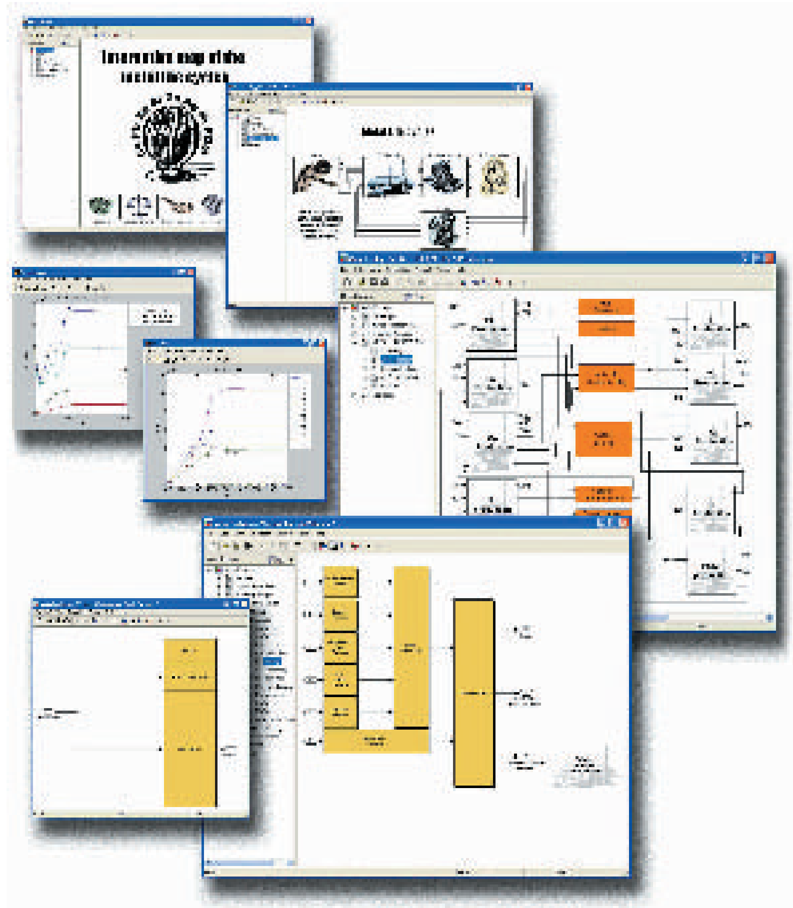


Fig. 2: Dynamic Simulink model to simulate the interactions between metal flows.

Fig. 2 : Modèle dynamique Simulink pour simuler les intéractions entre les flux de métaux

Source: E. Verhoef - M. A. Reuter - G. P. J. Dijkema - A. Scholte [6, 7]

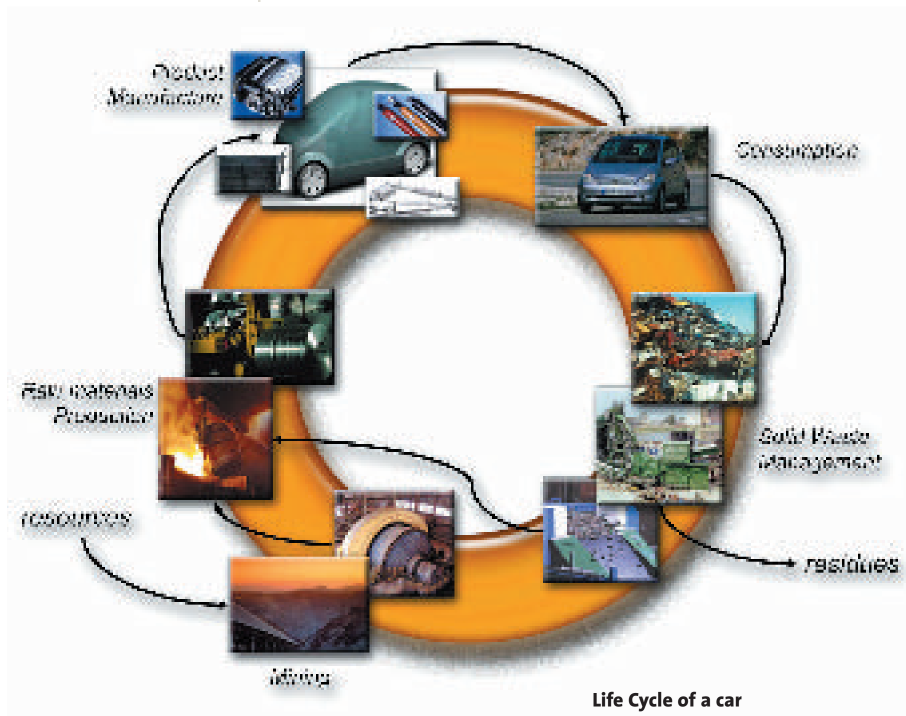
Only after suitable simulations (applying a dynamic system model programmed in Simulink [6, 7] - *Fig. 2*) and sensitivity analyses, a LCA can be performed. Impact assessment involves classification of the data from the inventory table into impact categories, characterisation and valuation. Valuation may only be valid within the defined system boundaries, as it depends on the local context of environmental status and on the temporal limits. For that particular aspect, metals may be stored in products for years and it is particularly important to consider the dynamic of their recycling, depending on the time limit.

“...an interconnected dynamic system model that:
► Interrelates the metal production systems of the major metals,
► Creates a static and dynamic model to provide outputs for environmental assessments,
► Links the metal industry with the waste infrastructure and end-of-life product processing...”

The Eco-indicator 99 method [4] can be used for impact assessment using the output of the dynamic system model. The underlying assumption of the so-called top-down method is that the weighting step is most critical and controversial one in the impact assessment. The weighting step should therefore be the starting point to develop damage models for the most important impact categories. This is in contrast to the bottom-up approach described in the ISO standards (14040 and 14042) where impact assessment is considered a way to improve the understanding of the inventory results.

However, as the top-down approach starts by defining the required result of the assessment, interpretation should be easier and less ambiguous. Based on the inventory table, software packages can be used to calculate the Eco-indicator damages.

However, a drawback of the Eco-indicator 99 method is that while the investigated metal production is a global system, the Eco-indicator method is based on the European situation. It is assumed that all emissions and land uses, and that all subsequent damages occur in Europe. Exceptions are the damages to resources depletion and the



Life Cycle of a car
Le cycle de vie d'une voiture
Source: E.Verhoef - Delft University of Technology (2004)

► Influence of metals consumption on their production circuits

Effects (Fig. 3) on the total metal production system for the SnZnBi solder: the demand for lead decreases (98.5%), while demand for zinc (100.1%), tin (115.2%) and bismuth (1190.6%) increases. As a consequence, the figure shows the impact on the supply and consumption (and thus disposal) of intermediates. The present surplus of bismuth intermediates is reduced, because its supply from lead production dwindles, while bismuth production increases. In the base situation only a small portion of the bismuth production comes from other intermediates in proportion to the lead intermediates. Thus, intermediates from the production of other metals must be found, for example from tin production *(see the metal wheel - Fig. 1)*. This example shows a paradox: bismuth is to replace lead in solder, but lead is its source. In the model, this paradox is solved by assuming that new resources for bismuth can be found. If bismuth is produced from intermediates, effect on resources depletion will be minimal.

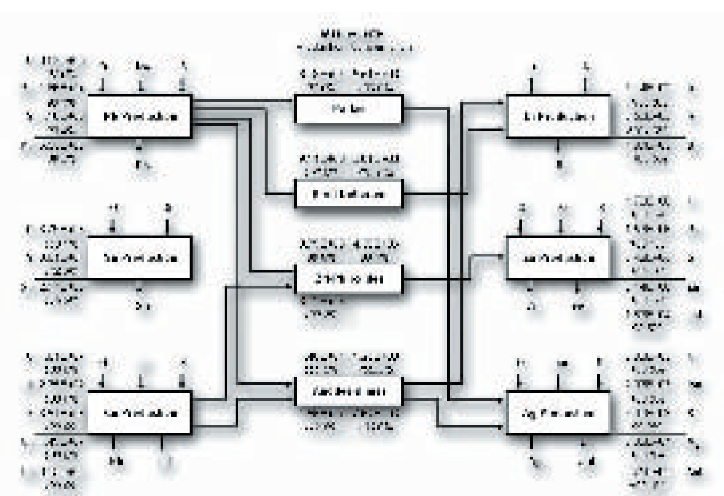


Fig. 3: Mass flows in the global metals production system at t=0 (tons/year in 2000);
Legends: O= ore, ly= intermediate from (y) other metal production circuits, S = old scrap.
Parkes (silver removal), Kroll-Betterton (bismuth removal), Zn/Pb oxides and Anode slimes are intermediates.
Fig. 3 : Flux de métaux dans le système de prodution global à t=0 (tonnes/an en 2000).
Légende : O = minerai, ly = flux intermédiaire venant du circuit de production d'un autre métal (y) ; S = résidus anciens.
Parkes (extraction de l'argent), Kroll-Betterton (extraction du bismuth), les oxydes de Zn/Pb et les boues anodiques sont des intermédiaires.
Source: E. Verhoef - M. A. Reuter - G. P. J. Dijkema - A. Scholte [6, 7]

damages created by climate change, ozone layer depletion, air emissions of persistent carcinogenic substances, inorganic air pollutants that have long-range dispersion, and some radioactive substances. It underlines once again the need of a clear system definition within which the results have a meaning.

Conclusion

The objective of EU waste policy is to *reintroduce* used materials into the economic cycle, especially by recycling, or to return them to the environment in a *useful* state or at least a *harmless state*.

To support decision-making in complex systems, the standardised ISO 14040 life cycle assessment (LCA) method can be used to quantify and to interpret the environmental repercussions of (changes in) a product system from cradle to crave related to a functional service unit. The use of the standardised LCA method at European level can be characterised as a damage-oriented or top-down method, which is often used in product design.

Winning, extraction and processing of metals are part of the interconnected worldwide metals production system. This complexity cannot be dealt with using LCA. Two types of primary metals can be distinguished: carrier and downstream metals. Carrier-metals deliver their co-elements in their primary production and in their recycling allow removal of same co-elements from diverse types of materials to be recycled. By reducing the capacity for primary and secondary production of carrier metals, input and recovery capacity of the downstream metals in the networked production system are unavoidably removed. The environmental repercussions of these actions are not included in *damage-oriented* LCA-scores.

Thus the focus is to be set on the system definition allowing an inventory analysis of metals in a *problem-oriented* approach. This can be achieved by developing an interconnected dynamic system model that links the metal production systems of the major metals and links the metal industry with the waste infrastructure. This should provide results to feed the LCA methodology to calculate the environmental impact. ■

> *“The objective of EU waste policy is to reintroduce used materials into the economic cycle.”*

Recycling of the end of life cars to feed the metals care
Recyclage des véhicules hors d'usage pour alimenter le cycle des métaux
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L'objectif de la politique européenne en matière de déchets est de réintroduire les matériaux dans le cycle économique, spécialement par recyclage, ou de les retourner à l'environnement dans un état utile ou au moins dans un état inoffensif.
Pour aider à la décision dans des contextes complexes, la méthode normalisée ISO 14040 d'analyse du cycle de vie (ACV) peut être utilisée pour quantifier et interpréter les répercussions environnementales des chaînes de production. L'utilisation de la méthode ACV standardisée à l'échelle européenne est orientée vers les dommages, de l'amont vers l'aval, ce qui est l'approche traditionnelle dans la conception des produits.
Dans le cas des métaux, l'extraction, le traitement et l'élaboration font partie d'un système mondial interconnecté de production dont l'ACV traditionnelle ne peut rendre compte. En effet, deux principaux types de métaux peuvent être définis : les porteurs et les associés. Les porteurs amènent leurs co-éléments dans le système métallurgique.
En réduisant les capacités de production primaires et secondaires des métaux porteurs, les capacités de récupération des métaux associés sont inévitablement réduites.
Les répercussions environnementales de ces actions ne sont pas incluses dans les résultats des ACV.
Ainsi, l'accent doit être mis sur une définition des systèmes qui autorise l'analyse de l'inventaire des métaux dans une approche orientée vers le problème. Cela peut être réalisé en développant un modèle dynamique des systèmes interconnectés qui relie les systèmes de production des métaux majeurs, et les infrastructures de traitement et recyclage des déchets. Ce modèle pourrait fournir les résultats aptes à alimenter la méthode ACV pour calculer les impacts environnementaux. C'est seulement de cette façon que la complexité des flux de matière peut être appréhendée et aider à l'élaboration de la réglementation environnementale.

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